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A Materials Substitution Feasibility Study for an Advanced Integrated Collective Protection System

by David M. Spagnuolo, Robert B. Dooley,
Travis A. Bogetti, and Elias J. Rigas

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Weapons and Materials Research Directorate, ARL

Abstract

This report documents the efforts involved in determining the feasibility of substituting aluminum components with organic matrix composites for application to the Advanced Integrated Collective Protection System (AICPS) container. The AICPS container houses an air filtration/power generation system capable of providing a temperature-controlled air supply free of nuclear, biological, and chemical (NBC) contaminants to tactical vehicles and shelters.

This study was undertaken to investigate the potential of enhancing the performance of the AICPS container in terms of portability (weight), economy (cost and life cycle), detection, and reliability (noise and electromagnetic impulse/interference protection). The objective was to determine if composite materials would enhance system performance and, if so, to what degree and at what cost.

Efforts to maintain original system geometry and performance specifications resulted in two approaches. Results indicate that the application of certain composites to the AICPS container would enhance performance in terms of weight. However, the increased cost of both the raw materials and of manufacturing the structure, subject to the geometric constraints, was considered inefficient. A significant increase in weight savings could be achieved, at a more reasonable cost, if geometric constraints were eliminated to allow for rearranging the distribution and orientation of internal components.

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1. Introduction

The U.S. Army Research Laboratory (ARL) Weapons and Materials Research Directorate (WMRD) was tasked to perform a material substitution feasibility study for the Advanced Integrated Collective Protection System (AICPS). This effort was initiated and sponsored by the U.S. Army Edgewood Research, Development, and Engineering Center (ERDEC) in an attempt to improve the AICPS performance through the use of advanced lightweight materials. The objective of this study was to provide alternative material solutions and suitable manufacturing methods for the replacement of the current aluminum structure used throughout the AICPS container. This effort provided the costs and weights for selected materials/designs and demonstrated whether the substitutions were feasible. The current container is made of aluminum box beam stock and aluminum skins. The total weight of the system, including frame and skins, is approximately 1,650 lb. The AICPS container is shown in Figures 1–4 on the following pages.

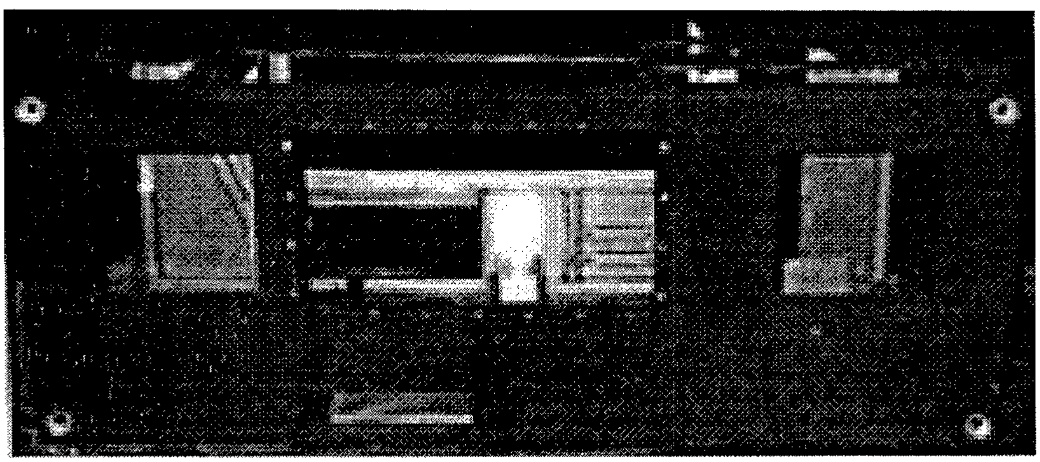

Figure 1. Rear View of AICPS Container.

Composites have played a major role in enhancing military systems by means of efficiently distributing load-bearing materials and optimizing properties as required for particular applications. The use of composites allows materials to be tailored for maximum strength-to-weight ratios, thereby reducing the quantity of materials used and consequently lowering manufacturing costs. In this

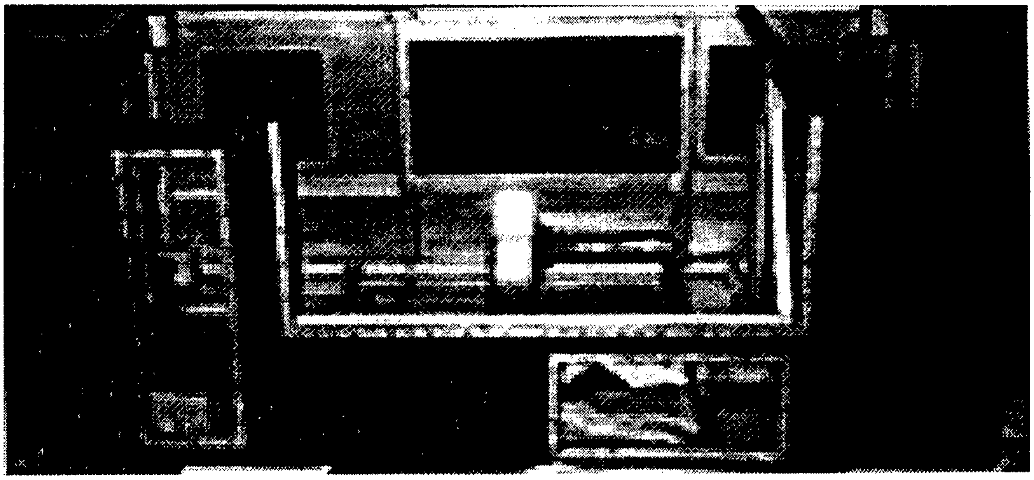

Figure 2. Front View of AICPS Container.

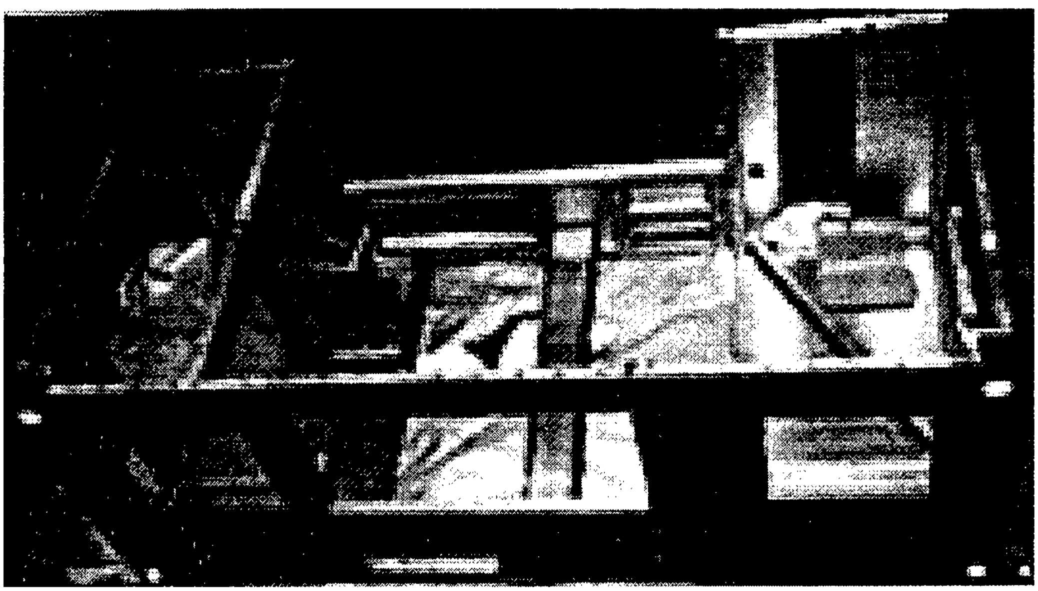

Figure 3. Overhead View of AICPS Container.

application, organic matrix composites reinforced with graphite and glass fibers were examined as substitutes for the aluminum box beams and skins of the AICPS container. Weight, cost, and manufacturing methods were the prime issues of interest in the evaluation of these alternative materials.

Figure 4. AICPS Mounted on High-Mobility, Multipurpose, Wheeled Vehicle (HMMWV).

Two approaches were used to evaluate alternative materials. One approach was to identify each individual component of the existing container, characterize the mechanical properties of the component, and evaluate a composite replacement in terms of weight and cost. This exercise was performed for both graphite and fiberglass. Issues such as mechanically joining beams and bonding skins were also examined in an effort to summarize the design for weight and cost evaluations.

The second approach used in this study was to match the performance of the assembled structure in terms of maximum allowable displacement. For the aluminum AICPS container, the maximum allowable displacement at the center (midspan with respect to stationary supports) was reported to be approximately 1/8 in. A finite element analysis (FEA) model was generated for this purpose, using a simplified geometric representation of the current AICPS container. Internal components dictated the model geometry, and actual component weights were used in the analysis. Amplification factors (experimentally determined accelerations) were used in the static analysis to compensate for dynamic loads.

2. Overview of Composites

By definition, composite materials are a category of materials consisting of two or more discrete materials, each possessing unique properties and distinct physical boundaries, bonded together and subsequently producing a single chemically nonhomogeneous solid. Fiberglass/epoxy, for example, is a composite material that consists of very fine glass fibers embedded in an epoxy resin. In this case, the glass fibers and cured resin each has its own chemical and material properties. In the form of a cured composite, the macroscopic solid exhibits its own set of unique properties and material characteristics that could not be achieved independently by either the glass or the resin. In general, composites are engineered to enhance the mechanical characteristics or properties of the resulting structure.

In most cases, composite materials consist of two main phases: the reinforcement and the bonding matrix. The reinforcing material is generally a network of high-tensile or high-modulus fibers. Common commercially available fibers such as carbon, various types of glass, and special application tradename fibers such as Kevlar (aramid fibers made by DuPont) and Spectra (polyethylene fibers made by Allied Signal) constitute the majority of reinforcement fibers in structural-grade composite materials. The primary function of the reinforcing fiber is to contribute the characteristics of high-strength and load-bearing capacity. Numerous variations of composite materials exist where the reinforcement material may be in the form of glass microspheres, short discontinuous randomly oriented fibers, randomly oriented long fibers, or long continuously oriented (parallel, woven, or wound) fiber arrangements. The reinforcing fibers embedded in the composite are set in both position and orientation by what is referred to as the matrix material.

The matrix is the second main material in a composite. In the practical sense, the matrix can be thought of as being the bonding agent or glue through which the higher strength reinforcing materials act. The primary functions of the matrix are to maintain the position and orientation of the fibers and to aid in transferring loads from fiber to fiber. Matrix materials also act to protect the fibers from abrasion and environmental damage such as chemical corrosion and humidity. In the previous fiberglass/epoxy example, the cured plastic resin enhances the performance of the composite material by offering a toughness or resistance to fracture that could not be obtained by the glass alone. The comparably higher strength glass fibers set in the tough plastic resin act together to achieve both strength and toughness in a solid form, thereby qualifying the resulting composite as suitable for structural applications.

2.1 Fibers. High-strength or high-modulus fibers function as the primary load-bearing members in fiber-reinforced composite materials. Fibers typically occupy the majority of the volume fraction in structural composite materials and are oriented and distributed according to the desired performance of the material for a specific application. Individual fibers vary in diameter but are generally in the range of 5–10 μm for carbon, roughly 10 μm for glass, and as large as 140 μm for metal fibers referred to as whiskers (such as boron or silicon-carbide). Because of their fine diameter, fibers are generally grouped into bundles called strands. Dry fiber products are commercially available in a variety of configurations including spools of strands, multiple strands called tows, cloth sheets or mats called woven roving, and also resin-impregnated fabrics called tape or prepreg.

Strengths of fiber vary according to type or chemical makeup but in general are high strength and relatively stiff and brittle. Table 1 lists some of the more common fibers and demonstrates typical strength and stiffness properties.

2.2 Resins. There are many types of resins available that are used in the manufacturing of composite materials. Resins are categorized as either thermoplastic (capable of being reshaped by melting and cooling) or thermoset (cured by heat or chemical means into an infusible or insoluble material). The resin or matrix contributes very little to the tensile properties but plays a major role in the shear properties of composites. The matrix adds to the compressive strength of a composite by providing lateral support to the fibers, thereby preventing buckling. Also, the physical characteristics of the matrix material, such as viscosity, melting point, and curing temperature, play a major role in the process ability and potential formation of defects in a composite.

Table 1. Properties of Common Reinforcing Fibers[a]

Fiber	Tensile Modulus ($\times 10^6$ psi)	Tensile Strength ($\times 10^3$ psi)	Strain to Failure (%)	Common Form/Name
E-glass	10.5	500	4.8	fiberglass
S-glass	12.6	625	5.0	fiberglass
AS-1	33	450	1.32	graphite
AS-4	36	590	1.65	graphite
Kevlar	19	525	2.8	Kevlar
Spectra 900	17	375	3.5	extended chain polyethylene

Note: All values are an average of single-filament tests performed in accordance with ASTM D3379-75.
[a] Data extracted from Mallick [6].

Some of the most commonly used resins for commercial and research applications are shown in Table 2.

Epoxy resins are commonly employed in structural parts and complex forms. They function as potting compounds, adhesives, and complex molding tools. Epoxy resins (specific gravity 1.2–1.3) have a wide variety of properties due to the large number of starting materials, curing agents, and modifiers available. Some of the other advantages of using an epoxy over other thermosets are the low shrinkage during cure (1–5%), no volatiles released during cure, its excellent adhesion to a wide variety of fibers, and its excellent resistance to chemicals and solvents. The disadvantages associated with epoxy resins are its relatively high cost and long cure times, although accelerators can be used to speed up a slow reaction and shorten the cure time.

Polyester resins are used in the manufacturing of a broad range of products, including boats, golf club shafts, fishing rods, appliances, structural parts for automobiles, building panels, and aircraft. Polyester resins (specific gravity 1.1–1.4) possess a wide range of properties from hard and brittle to soft and flexible. Though their properties are generally lower than epoxies, some advantages (such as low viscosity, fast cure time, and low cost) make them the material of choice. The principal

Table 2. Matrix Materials[a]

Material	Application
Thermoset Polymers (resin)	
Epoxies	Principally used in aerospace and aircraft applications.
Polyesters, Vinyl Esters	Commonly used in automotive, marine, chemical, and electrical applications.
Phenolics	Used in bulk molding compounds.
Polyimides, Polybenzimidazoles (PBI), Polyphenylquinoxaline (PPQ)	For high-temperature aerospace applications (temperature range: 250–400° F).
Thermoplastic Polymers	
Nylons (such as nylon 6, nylon 6, 6) Thermoplastic Polyesters (such as polyethylene Terephthalate [PET], Polybutylene Terephthalate [PBT]) Polycarbonates (PC) Polyacetals	Used with discontinuous fibers in injection molded articles.
Polyamide-Imide (PAI) Polyether-Ether Ketone (PEEK) Polsulfone (PSUL) Polyphenylene Sulfide (PPS) Polyether Imide (PEI)	Suitable for moderately high-temperature applications (temperature range: 300–500° F).

[a] Data extracted from Mallick [6].

disadvantage of polyesters is their high shrinkage (5–12%). Although this aids in the release of parts from a mold, the difference in shrinkage between the resin and fibers may result in uneven depressions on the molded surface.

Vinyl ester resins, sometimes referred to as a cross between an epoxy and polyester resin, possess good chemical resistance and tensile strength along with a low viscosity and a fast cure time. This low viscosity makes vinyl ester a popular choice for the resin transfer molding (RTM) process.

However, the high volumetric shrinkage (5–10%) and moderate adhesive strength give way to epoxies in performance applications.

2.3 Prepregs. Prepregs are thin sheets of aligned fibers, preimpregnated with specific quantities of resin, that form a pliable cloth or tape. The tape is generally stacked at specified orientations to the desired thickness over a tool or mold. The curing (hardening) of the prepreg occurs on the tool generally in an oven or autoclave or by means of heat lamps or other external initiator. By these means, the degree of curing advances from the B-stage (precrosslinked) to the final crosslinked stage to produce an insoluble part. There are various forms of commercially available prepregs including mats, continuous rovings, or woven fabrics. The resin content of prepregs is typically in the range of 30–45 weight-percent, depending on the intended application. Epoxy is the primary resin material of choice for most prepregs, although other thermoplastic and thermoset resins are also used. Prepreg sheets come in various widths, and a typical cured ply thickness for a unidirectional epoxy composite laminate is in the range of 0.005–0.010 in. The advantage of prepregs is the elimination of the processing step of wetting out the fibers. The disadvantages are their higher costs, their need for refrigerated storage of thermoset resins, and their relatively short shelf life when out of the freezer.

2.4 Composites Processing Methods. There are several manufacturing processes available for fiber-reinforced composites that are suitable for the components pertaining to this system. Methods under consideration in this study such as hand lay-up, filament winding, pultrusion, and RTM were investigated as potential methods to manufacture beams and panels.

Hand lay-up is the application of laying prepreg or dry fiber mats onto a male or female mold of the desired shape. This involves cutting fabric to size, then applying the fabric onto the mold. Resin must be applied to each individual ply after it is laid into position. The part is then vacuum-bagged, subjecting the mold and wetted fabric to compression by means of atmospheric pressure. Curing of the part generally occurs in an autoclave or oven although there are also room temperature curing resin systems. Finally, the finished parts are removed and demolded (separated from the tool). Prepreg lay-up operations are similar to hand lay-ups, the difference being that the fiber or fabric is already impregnated with resin, thereby resulting in fewer steps to manufacture the part. Using prepreg can reduce fabrication time, but it is significantly more expensive. Hand lay-up and prepreg lay-up techniques are manually intensive processes and have drawbacks such as low production rates and the need for skilled labor. Automated prepreg tape lay-up machines are available for a limited number of applications and material types, but there is a large capital investment associated with the purchase of this type of equipment.

Filament winding, on the other hand, combines a moderate rate of production with a high rate of reproducibility. Filament winding is a process where continuous rovings or monofilaments are wound over a rotating mandrel. Specific part properties can be achieved by controlling the winding angle (fiber orientation with respect to the mandrel). These angles can vary from 0–90°, depending on the requirements. In the filament winding process, the fiber is impregnated with resin by being pulled through a liquid resin bath while under tension. The wetted fibers are then spun onto the mandrel in either a repeating pattern or adjacent bands to cover the mandrel surface. The part is then cured and removed from the mandrel.

Composite processing by means of pultrusion provides a high production rate, high reproducibility, and low cost. The pultrusion method is a continuous process in which dry fiber is pulled through a resin bath and then through preforms of the desired shape. Preforms are used to gradually form the fiber bundles into the desired shape to allow easier entry into the die. Finally, wet preshaped fibers enter a heated die for curing. Most of the pultruded shapes, whether solid or hollow, result in unidirectional fiber orientations. Recent advancements in pultrusion processing, however, enable the processor to use fabrics to tailor the properties of these profiles to fit a wide scope of engineered and structural requirements.

RTM is a closed mold operation that provides two high-quality surface finished parts. The RTM process begins by cutting reinforcement to the desired shape and size, then laying the reinforcement into a mold. The mold is closed, and resin is injected or transferred into the mold, completely wetting out (impregnating) the enclosed reinforcement. The resin injection system is a high-pressure pump that mixes the resin and catalyst together just before entering the closed mold. As the resin works its way through the mold and reinforcement, entrapped air is pushed out through vent holes located around the mold. Most RTM applications use a room temperature cure polyester or vinyl ester resin, but resins that cure at elevated temperatures can be used if the RTM machine has a heated mold for curing. Vacuum-assisted RTM (VARTM), which is a variation of the traditional RTM process, can also be performed using a one-sided mold and a vacuum bag. This method is accomplished by using a vacuum to pull the resin from one side of the part to the other, impregnating the reinforcement and removing air along the way. This can be accomplished in a closed mold or a one-sided mold using vacuum-bagging techniques. The one-sided method reduces mold costs, but is more time consuming than conventional RTM due to the bagging steps required. RTM or VARTM would both be suitable methods for making the side panels in this application. This process can be used for making the sandwich structures as well as composite panels [1]. Table 3 shows some of the economic and design factors associated with the various processing methods (taken from Lubin [1982]).

3. Composite Frame by Material Substitution

A major effort was undertaken to review the current AICPS container design. Each major structural member was identified, itemized, and characterized in terms of four main mechanical properties. Calculations were performed to determine (1) buckling strength, (2) bending stiffness, (3) axial stiffness, and (4) compressive/tensile strength of each member (see Appendix B). Since some of the previously mentioned criteria are functions of length and not exclusively cross section, each beam was evaluated individually. Properties of composite materials were used in the design of beams and panels to arrive at cross sections that would match the performance of all structural members identified. This exercise was performed for both fiberglass and graphite-reinforced composites. In each case for the composites, a single minimum cross section capable of performing as well as the aluminum was evaluated in terms of total weight and cost for all beams in the structure.

Several composite manufacturing processes were examined for beams used in this particular application. Since the current design was structurally adequate for its intended purpose, a "one-for-one" substitution (qualified by satisfying all four criteria) would provide the same strength and

Table 3. Economic and Design Factors for Laminates

Molding Process	Equipment Cost	Date of Production	Molded Part Strength	Importance of Operator's Skill	Part Complexity Possible	Part Reproducibility
Hand Lay-Up	1	3	3	10	9	1
Vacuum Bag	2	2	4	10	9	3
Pressure Bag	3	1	6	6	7	4
Spray-Up	4	4	3	10	8	1
Filament Winding	6	6	10	2	4	9
Pultrusion	7	9	9	2	2	10
SMC	10	8	7	4	9	10
Centrifugal	9	7	8	3	3	6
Continuous Laminate	10	10	5	2	1	10
Regin Injection	3	2	3	7	7	8
Injection	10	10	6	2	10	10
Shell Coating	9	4	3	5	7	9
Premix (BMC)	9	8	7	4	8	10

Note: 10 equals highest; 1 equals lowest.

deflection. The container was required to deflect no more than 1/8 in. The bending stiffness (modulus, E, times the moment of inertia, I) and the tension/compression stiffness (AE/L, where A is the cross-sectional area of the beam) were the limiting factors for most members using this approach.

Matching the product of "E" and "I" of the composite beams to that of the aluminum allowed for the theoretical determination of a satisfactory beam cross section. Commercially available beams of adequate dimensions and properties were examined for both graphite and fiberglass pultruded box beams. The moduli of the materials used within each beam were 10 Msi, 2.5 Msi, and 15 Msi, for aluminum, glass, and graphite, respectively. These values were chosen for performing calculations based on vendor data for each of the pultruded shapes. The Morrison Molded Fiber Glass (MMFG)

Company's design manual and shape index were used to obtain the required beam dimensions. See Appendix A for a list of other possible manufacturers and vendors for components.

Results of selected beam property requirements are shown in Appendix B for the original aluminum design, a fiberglass substitution, and a graphite substitution. The component designation numbers in these charts (i.e., SH2 No. 3) identify each beam as it was measured from the engineering drawings. For instance, SH2 No. 3 represents a beam designated as No. 3 from drawing titled "sheet 2."

The total weight of each solution is shown on the bottom of each chart set. These charts provide a means of comparing properties, price, and weight. As can be seen from these charts, all properties for the fiberglass and graphite designs are equal to or greater than the aluminum design. The bending stiffness and axial stiffness calculated from aluminum beam data provided a means for calculating beam dimensions required for the composite solutions. For example, in the case of the fiberglass box beams, the bending stiffness (EI) was calculated using the following equation:

$$(EI)_{AL} = (EI)_{GL}$$
$$1.765 \times 10^6 = (2.5 \times 10^6)\, I \Rightarrow I = 0.71.$$

Reviewing cross-sectional properties, from MMFG and other commercial composites manufacturers' literature, resulted in the selection of a hollow box beam with dimensions of 2 in × 2 in × 0.25 in with an I of 0.91 (a value of 0.71 or greater is required for the design). It should be noted, however, that in the manufacturers' literature, the term "commercially available" means the company has a die available to make a particular-shaped (dimensioned) beam.

It appeared that these beam dimensions were sufficient for this application due to the fact that the bending stiffness of this glass beam was 20% greater than that of the aluminum beams. To satisfy axial stiffness requirements, however, a beam with dimensions of 2.5 in × 2.5 in × 0.25 in would be required. Under these circumstances, the fiberglass system (frame beams only) was heavier than the current aluminum design (see Appendix B).

The graphite frame, though more expensive than the aluminum, is a more suitable material due to the weight savings involved. Graphite provides superior properties, while utilizing smaller beams—namely, 1.25 in × 1.25 in × 0.125 in (see Appendix B).

Due to the complexity of some of the corner castings, it is recommended that the current aluminum joints also be used for the composite design as well. Manufacturing the more complex corner (joint) shapes using composites could be done but would be would be significantly more expensive than aluminum. Burnham Products, Inc., was found to be a qualified cost-effective manufacturer of the less complex composite corner shapes that could be used in tandem with the more complicated aluminum castings.

Fastening or bonding of the frame beams to the structural side panels could be achieved most effectively through the use of an adhesive system. A large selection of adhesive systems are qualified for this application; for instance, 3M has two systems that are suitable for the job—namely, DP420 and DP190. These are two-part epoxy systems consisting of a base and an accelerator. These adhesives are capable of bonding both composite to composite and composite to aluminum. They have a temperature service range of -67°–350° F, excellent environmental/chemical resistance, and good shear-strength properties. To assure quality bonds, it is recommended that the bonding surfaces be prepared by either light abrasion or degreasing with a solvent such as isopropyl alcohol.

There were several factors influencing U-channel (engine mounts) material selection. For instance, fiberglass U-channels required for this application weigh 1.40 ft/lb and cost approximately $6.25/ft to manufacture (not including setup charge). The setup charge is an expense incurred by the manufacturer for preparing a machine for pultruding a particular shape. This price is based on a minimum mill run of 2,500 ft, and anything less than that is priced according to the percentage of that mill run ordered. For graphite channels, cost increases by a factor of approximately 3. Again, these prices were based on typical mill runs and would increase dramatically for the amount required for this application.

In the case of the engine-mount application, however, aluminum is most appropriate due to its superior fatigue properties relative to both fiberglass and graphite. For this reason, and due to the fact that only two beams are required per AICPS system, aluminum is the recommended material for mounting the motor as well as other dense vibrating components.

4. Composite Side Panels

There are numerous composite side panel configurations that are suitable for the AICPS application. This study examined some of the more common selections and provided advantages, approximate cost, and weights for each. One type of panel construction available consists of glass and/or graphite "skins" with a honeycomb or foam-type core. Honeycomb is a synthetic, calendered paper produced exclusively by DuPont under the trade name Nomex. It is tough, impact resistant, and very lightweight. The "expanded" core creates cells that result in an anisotropic material, and the resulting directional properties should be adapted to the anticipated loads. The core is dip-coated with a suitable resin after having been expanded to the desired size. The resin coated honeycomb is then adhesively bonded to thin, lightweight skins (most commonly glass or graphite), resulting in a sandwich-type structure.

Honeycomb sandwich panels, such as aircraft flooring sections (manufactured by M.C. Gill Corporation), could be used as AICPS container panels. Selection of the core skins (E-glass, S-2 glass, or graphite) affords tailoring the panels to unique properties as required for the intended application. The use of S-2 glass provides high-impact resistance, corrosion resistance, and high tensile strength. Graphite provides reduced weight and high stiffness. Panels of this type, with either fiberglass or graphite skins, would enhance noise suppression capabilities as compared to the current aluminum shear skins. The disadvantages of using graphite are lower impact resistance, galvanic corrosion, and higher cost than both aluminum and fiberglass.

Typical panel weights using graphite and/or fiberglass face sheets and Nomex honeycomb cores are shown in Table 4. Based on outside AICPS container dimensions, the weight for the front and

Table 4. Panel Construction Weights[a]

Construction	Panel Thickness (in)	Core Density (PCF)	Panel Weight (PSF)	Total Weight Panels (uncut) (lb)	Total Weight Panels With Cut-Outs (lb)
Graphite Facing/Honeycomb Core	0.400	4	0.42	37.8	26.5
FRP[b] Facing/Honeycomb Core	0.400	5	0.52	46.8	32.7
FRP Facing/Honeycomb Core	0.400	9	0.64	57.6	40.2
FRP-Graphite Face Honeycomb Core	0.400	8	0.58	52.2	36.45

[a] Extracted from M. C. Gill Doorway Corp. [7].

[b] Fiberglass-reinforced plastic

back panels is (determined to be) 6.74 lb each. Top and bottom panels are determined to weigh 8.75 lb each, and side panels weigh 3.41 lb each. These weights are for the panels only and do not include any of the necessary cutout details, fasteners, or electromagnetic impulse (EMI) shielding. EMI shielding, based on similar shielding used in the Composite Armored Vehicle (CAV), weighs approximately 0.169 lb/ft^2. Integration of EMI shielding results in slightly heavier panels (9.45 lb for front/back, 12.27 lb for the top/bottom, and 4.78 lb for the end panels). Total weight of panels required for the entire container including EMI shielding is 53 lb.

Estimated weight for the six side panels (graphite faced and honeycomb core) is approximately 38 lb. The same panels including EMI mesh protection weigh 53 lb. Replacing the graphite skins with E-glass skins, including the weight of the EMI mesh, increases the panel set weight to 62 lb. Hybrid panels incorporating both fiberglass, for galvanic corrosion protection, and graphite, for greater structural integrity, weigh approximately 67 lb per AICPS container set (including EMI shielding).

Also available from Nida-Core Corporation is a phenolic (high-temperature synthetic resin) foam-filled honeycomb core for improved fire resistance as well as a polyurethane foam-filled core offering greater insulative properties. These panels are available in thicknesses from 3/16 in up to and including 18 in. Panels of this type provide excellent impact resistance, outstanding bonding properties, and higher fatigue resistance. Foam-filled cores contribute roughly 1.87 lb/ft^3 to the weight of a foam-filled panel.

In addition to those mentioned previously, there are numerous foam core panel configurations available that could improve container performance in terms of weight, stiffness, noise/signature suppression, or EMI protection. However, a basic fiberglass or graphite laminate panel offers most of the same advantages at a much lower cost. For the AICPS application, foam core panel alternatives would significantly increase system cost for disproportionately few property enhancements.

Similarly, there are tradeoffs associated with the choice of materials used for laminated container panels. The most economical solution would be to use E-glass fabric with epoxy or polyester resin. The E-glass panel thickness required to match the strength and stiffness of the aluminum is 0.16 in as calculated as follows [8]:

$$T_A = T_B I_A \div I_B,$$

where

T_A is unknown thickness for woven roving hand lay-up,
T_B is the existing aluminum thickness = 0.095 in,
I_A is hand lay-up woven roving thickness index (stiffness) = 0.78, and
I_B is the aluminum thickness index (stiffness) = 0.46.

Choosing a graphite laminate reduced weight at the expense of cost. The average density for carbon fiber is 0.065 lb/in^3. Due to the stiffness properties associated with carbon fibers, the thickness of these panels decreased to a 0.10 in or less. System costs and weights are summarized later in the Cost Analysis Section of this report.

5. Stiffness Performance and Material Selection

A finite-element model of the AICPS support structure was developed to evaluate its overall deflection response (stiffness) for various potential candidate materials, which would be considered to replace the current baseline aluminum design. It is noted that no attempt was made here to "redesign" the current structure as this study is only intended to make relative comparisons in stiffness performance as a function of material type. The materials considered in this study are (1) baseline aluminum, (2) unidirectional graphite/epoxy, (3) graphite/epoxy fabric, and (4) titanium. Details of the investigation are provided in suceeding text. Based on preexisting geometry-related design constraints imposed by the current configuration, the composite systems investigated were not found to offer substantial gains in the overall stiffness above that of the aluminum structure. This observation is attributed to the fact that the transverse shear stiffness in the beams (a weak direction for the composite systems) contributes substantially to the load-carrying ability of the AICPS structure. To reinforce this fact, a stiffer, homogeneous metallic titanium structure was modeled and was found to offer substantial performance gains over the baseline aluminum design. The findings here suggest that unless a significant redesign of the current aluminum configuration (geometry) is made, the full potential stiffness and strength benefits offered by fiber-reinforced polymer composites may not be fully exploited in this application.

5.1 Analysis

5.1.1 Model Geometry. The geometry of the finite-element model employed in this investigation was an approximation of the actual AICPS structure. The finite-element representation of the structure was composed of beam elements only and neglected the load-bearing contributions of the face sheet components. ABAQUS [2] beam elements of the type B32 were used (three-noded beam elements that account for transverse shear and axial deformation). A total of 250 elements were used in the model. The beam model used is shown in Figure 5. For each material type considered in this investigation, the cross-sectional geometry of the box beams used in the model was held constant and equal to those referenced for the baseline aluminum design prepared by the Foster Engineering Co. [3]. It is noted that two additional cross members, which do not exist in the actual AICPS structure, were added to the floor of the structure to increase lateral twisting stiffness.

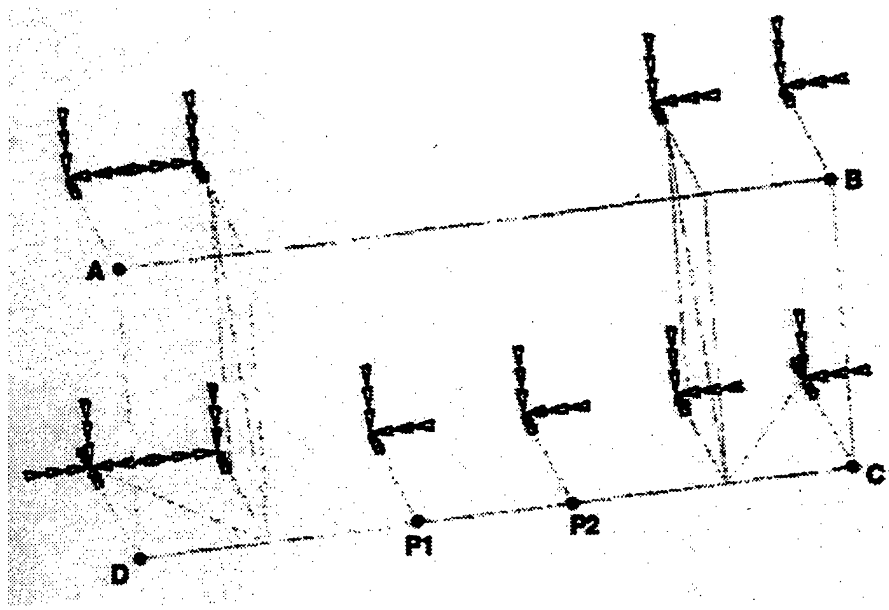

Figure 5. The Finite-Element Beam Model, Boundary Conditions, and Load Introduction Points.

5.1.2 Loading/Boundary Conditions. All beam elements were assumed to be rigidly connected at their respective points of contact. The rear of the AICPS structure (beam model) was assumed to be rigidly attached to the adjacent supporting wall structure (see Figure 5).

Two different load cases were considered in this study: vertical bending (about the global X-axis) and lateral twisting (about the global Y-axis). A static load equivalent was calculated for the structure and applied at two central locations (P1 and P2) within the model (see Figure 5). The magnitude of the load was based on information [3] for the aluminum design. Namely, a total structural weight of 1,650 lb was assumed with accelerations of 4 g for vertical bending and 3 g for lateral twisting. This corresponded to statically applied force loads of 6,600 lb and 4,950 lb, respectively.

5.1.3 Materials. As mentioned previously, four different materials were considered in this study: (1) baseline aluminum [3], (2) unidirectional graphite/epoxy, (3) graphite/epoxy fabric, and (4) titanium. The properties used for each of these materials are listed in Table 5. The 1-direction corresponds to the axial direction in the beam. The 2- and 3-directions correspond to the transverse and normal directions of the beam, respectively. Both the aluminum and titanium materials were assumed isotropic.

5.2 Results. A finite-element analysis was conducted for each of the two load cases and for each of the four materials. For each load and material case, a maximum deflection was recorded to give an indication of the relative deflections of the various materials with respect to the aluminum baseline design. It is noted that despite the simplifying assumptions made in this analysis, the predicted deflection for the aluminum baseline model (0.0988 in) is reasonably consistent with the 0.1250 in allowable suggested by Lockheed Martin [4].

In order to make quantitative comparisons of the structural performance for each material and load case, a global stiffness for the entire AICPS structure was defined. This structural stiffness was based on the global X- and Y-direction deflections of the A, B, C, and D "corner" points on the model (see Figure 5). The vertical bending stiffness, K_y, was defined as $K_y = F_y/Y_{ave}$, where F_y is the applied vertical bending load (6,600 lb) and Y_{ave} is the average Y-direction deflection of the corner points A, B, C, and D in the model. The lateral twisting stiffness, K_x, was defined similarly as $K_x = F_x/X_{ave}$, where F_x is the applied lateral twisting load (4,950 lb) and X_{ave} is the average X-direction deflection of the corner points A, B, C, and D in the model. All vertical bending and lateral twisting stiffnesses were compared with the aluminum design and listed as a percentage difference from these baseline reference values.

The results are summarized in Table 6. For illustrative purposes, typical vertical bending and lateral twisting deflection responses are shown in Figures 6 and 7, respectively. It is noted that the

Table 5. Material Properties

Material	E_1 (psi)	E_2 (psi)	E_3 (psi)	n_{23}[a] (psi)	n_{13}[a] (psi)	n_{12}[a] (psi)	G_{23} (psi)	G_{13} (psi)	G_{12} (psi)
Aluminum	$10.0 \times 10^{+6}$			0.30			$3.85 \times 10^{+6}$		
Graphite/Epoxy (Unidirectional)	$15.0 \times 10^{+6}$	$1.33 \times 10^{+6}$		0.45	0.33		$0.46 \times 10^{+6}$	$0.72 \times 10^{+6}$	
Graphite/Epoxy (Fabric)	$12.0 \times 10^{+6}$	$2.80 \times 10^{+6}$	$1.50 \times 10^{+6}$	0.40	0.18	0.65	$2.30 \times 10^{+6}$		
Titanium	$16.0 \times 10^{+6}$			0.30			$6.15 \times 10^{+6}$		

[a] Nondimensional

Table 6. Finite-Element Results

Material	Y_{max} ($\times 10^{-2}$ in)	X_{max} ($\times 10^{-2}$ in)	K_y (lb/in)	K_x (lb/in)
Aluminum	9.88	25.47	$6.68 \times 10^{+4}$ lb/in (reference)	$1.94 \times 10^{+4}$ lb/in (reference)
Graphite/Epoxy (Unidirectional)	11.22	22.05	−13	+13
Graphite/Epoxy (Fabric)	9.41	23.26	+5	+9
Titanium	6.48	16.72	+34	+34

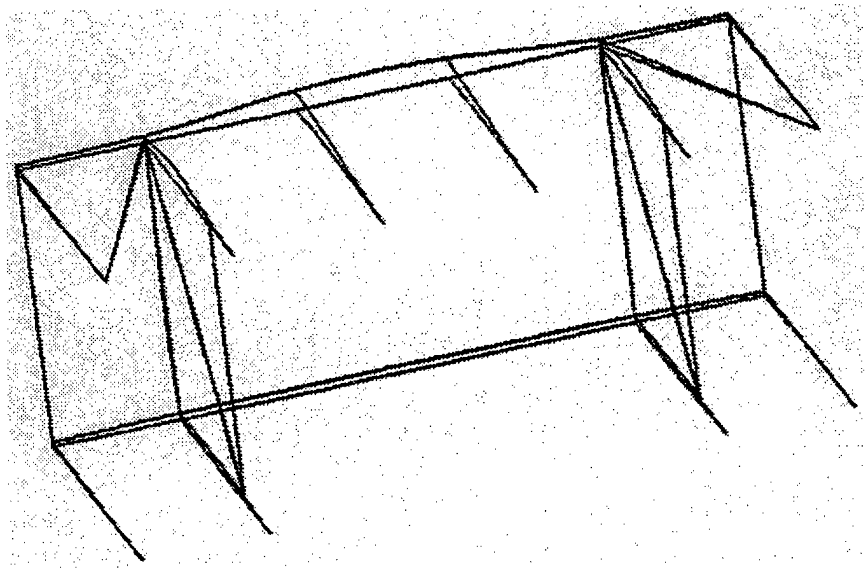

Figure 6. Vertical Bending Deflection Response.

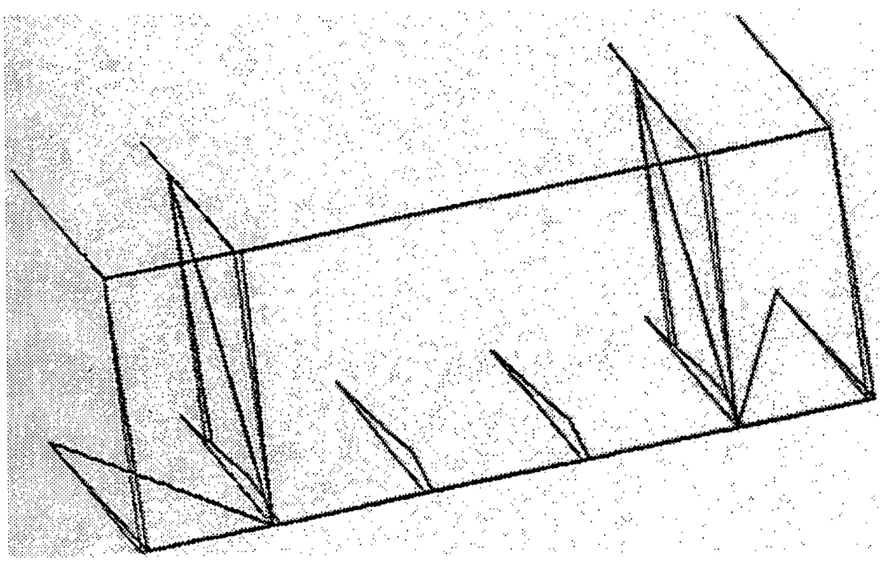

Figure 7. Lateral Twisting Deflection Response.

trends found in the relative maximum deflections of the corner points are reflected in the values given for the structural stiffness results. Both graphite/epoxy designs did not show any significant stiffening improvements over the aluminum design. For example, the graphite/epoxy fabric design only showed an increase in the vertical bending and lateral twisting stiffnesses of 5% and 9%, respectively. Although the graphite/epoxy unidirectional design showed a 13% increase in lateral twisting stiffness, it showed a sharp drop of 13% in vertical bending. The relatively small performance gains of the graphite/epoxy systems may not be significant enough to merit potential cost increases over the baseline aluminum design.

A titanium material example case was run and provided an interesting result. This material showed a significant 34% increase in structural stiffness over the aluminum design both in vertical bending and lateral twisting. The increased shear stiffness offered by the titanium material translates into an overall stiffer structure. This result demonstrates that the overall stiffness of the current AICPS design configuration is largely affected by the transverse shear stiffness of the box beams. It is noted that to fully exploit the high axial stiffness and strength of fiber-reinforced systems, a redesign of the current geometric configuration must be considered. This example also suggests that weight savings with a titanium design are possible but would require further investigation to include performance vs. cost trade-off studies.

6. Cost Analysis

Approximate cost assessments were tabulated for a series of AICPS container alternatives. Where commercial estimates were not available, costs were calculated based on ARL-WMRD operating and procurement data. Material common to most options, as well as that of the baseline (aluminum) structure, is itemized with unit costs as follows:

aluminum (1100 grade)...........	\$ 1.68/ft at 2,500 ft mill run
E-glass....................................	\$ 7.00/ft at 2,500 ft mill run
graphite....................................	\$ 10.00/ft at 2,500 ft mill run
setup charge............................	\$500.00–\$1,000.00 (range of cost per machine)
commercial cut-to-length.........	\$0.40 per order (single cut).

To obtain a reasonable estimate for the container panels, several important factors were taken into consideration. If a sandwich structure was chosen, price would depend on type of core material, type of skin material, incorporation of EMI shielding, encapsulation of edges, and machining cost for holes and cut-outs. Encapsulation of the edges refers to the process of applying an adhesive or resin coating, preferably a conductive type for EMI purposes, along the open edges of the panels. The cost of core material was based on square footage of panels ordered and ranged from approximately \$1.40 to \$1.75/ft^2. For the AICPS container, this amounts to an approximate cost of \$160.00 per system. Additional costs, such as purchasing skins, bonding skins to cores, and machining the finished sandwich panel would increase this cost significantly. Weights and prices for any special beams, U-channels, and four mounting brackets need to be included in all systems itemized as in Table 7.

7. Conclusions

The conclusions drawn from this study indicate that the AICPS container performance could be enhanced in terms of both weight and signature/noise reduction through the use of composites. A number of composite material systems would qualify successfully in the substitution for aluminum container components. The degree of enhancement in some cases was shown to be marginal at best while increasing the production costs significantly.

A finite-element model of the AICPS support structure was developed to evaluate its overall deflection response (stiffness) for various potential candidate materials, which could be considered to replace the baseline aluminum design. Several materials were considered in this study: (1) baseline aluminum, (2) unidirectional graphite/epoxy, (3) graphite/epoxy fabric, and (4) titanium.

Based on preexisting geometry-related design constraints imposed by the current configuration, the composite systems were not found to offer substantial gains in the overall stiffness above that of the aluminum structure. This observation is attributed to the fact that the transverse shear stiffness in the beams (a weak direction for the composite systems) contributes substantially to the load-carrying ability of the AICPS structure. To reinforce this fact, a stiffer, homogeneous metallic titanium structure was modeled and found to offer substantial performance gains over the baseline

Table 7. Material Price and Weight Estimates

System	Component Weight						Cost		
	Graphite Beams (lb)	Emi Mesh (lb)	Frame and Skins (lb)	Connectors (lb)	Hardware/ Adhesive (lb)	Total (lb)	Material ($)	Labor[a] ($)	Total ($)
A	34.39	15.25	46.80 (glass skins/ honeycomb core)	31.00	5.00	132.44	13,710.00	9.520.00	23,230.00
B	34.39	15.25	37.80 (graphite skins/ honeycomb core)	31.00	5.00	123.44	17,710.00	9,520.00	27,230.00
C	34.39	15.25	52.20 (glass/graphite skins/honeycomb)	31.00	5.00	137.84	15,410.00	9,520.00	24,930.00
D	34.39	15.25	74.00 (graphite fabric)	31.00	5.00	159.64	3,480.00	15,820.00	23,230.00
E	34.39	15.25	139.00 (glass fabric) (T = 0.16 i)	31.00	5.00	224.64	2,565.00	15,820.00	18,385.00

NOTE: See Appendix C for major processing steps involved for each system.
[a] Includes assembly, machining, etc.

aluminum design. These findings suggest that unless a significant redesign of the current aluminum configuration (geometry) is made, the full stiffness and strength benefits offered by fiber-reinforced polymer composites cannot be fully exploited in this application. Findings of this study also suggest that weight savings with a titanium design are possible, but would require further investigation to include performance vs. cost trade-off studies.

Tabulated cost and material options based on supplier cost quotes (or information from similar prototype fabrication efforts undertaken by ARL's WMRD) demonstrate the economic implications of choosing advanced materials for the current AICPS container. Prices were based on estimated labor charges required to manufacture 100 systems per year. These prices neglect any commercial overhead costs that may be incurred. The most cost-sensitive variable influencing unit price is driven by geometry (i.e., the cost per unit decreases as unit area increases [5]).

The lightest composite system examined was the graphite beam/graphite skin/honeycomb core sandwich structure. This system weighed approximately 123 lb but was also the most expensive. The glass/honeycomb system with graphite beams was less costly but was 10 lb heavier. A graphite beam frame with graphite or glass panels could be implemented as a compromise between weight and cost. Another method would be to incorporate the frame or composite panels, whether a sandwich structure or just composite, into the current aluminum system.

Swapping composite for aluminum in a one-to-one exchange is usually not an optimal solution and tends to drive up costs. The AICPS is very complex and would be costly as a composite application due to the many components in the structures current configuration. Alternative manufacturing methods would be to filament-wind or use a VARTM technique. Stiffeners would have to be added in order to rigidly fasten internal components where needed. An optimal solution would be a new ground-up design for a composite system.

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8. References

1. Dooley, R. "Composites Tutorial: From Racquets to Rockets." U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, unpublished.

2. Hibbit, Karlsson & Sorensen Inc. ABAQUS Software Package Theory Manual. Pawtucket, RI, 1996.

3. Foster, K. "Stress Analysis of the AICPS Structure." Report No. 96-019, Foster Engineering Co., Agoura Hills, CA, May 1996.

4. Perillard, P. Personal Communication. Lockheed Martin, 1996.

5. Jones, S. K., J. W. Gillespie, R. F. Eduljie, and A. Dhawan. "Integrated Model For Composite Armored Vehicle Cost Assessment." Computer simulation model, University of Delaware, Newark, DE, 1996.

6. Mallick, P. K. *Fiber Reinforced Composites.* Second edition, New York: Marcel Dekker, Inc., 1993.

7. M. C. Gill Doorway Corp. Company newsletter, vol. 29, no. 4, El Monte, CA, 1992.

8. Owens-Corning. "Hand Layup and Sprayup Guide." Publication No. 5-PL-13986, Toledo, OH, April 1986.

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Appendix A:

Suggested Manufacturers and Vendors for Components

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Suggested Manufacturers:

United Defense, L.P.
Ground Systems Division
2890 De La Cruz Blvd.
Santa Clara, CA 95052

Marion Composites
A Division of Technical Products Group, Inc.
150 Johnston Road
Marion, VA 24354

Suggested Vendors For Individual Components:

M.C. Gill Corp.
4056 Easy St.
El Monte, CA 91731

Product:	Composite Panels Composite Sandwich Structures

Composix Co.
120 O'Neill Drive
Hebron, OH 43025

Product:	Composite Panels Composite Sandwich Structures

Morrison Molded Fiber Glass Company
400 Commonwealth Avenue
Box 580
Bristol, VA 24203-0580

Product:	Composite Structural Shapes (Box Beams, U-Channels)

Burnham Products, Inc.
2700 S. Custer
P.O. Box 12950
Wichita, KS 67277

Product:	Composite Structural Shapes Composite Panels

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Appendix B:

Beam Weights and Costs

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AICPS Aluminum Chart

	Component	Length in	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb.	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH2 #2	27.29	0.1765	10,000,000	0.53	14.464	1.417	1,765,000	194210.33	3.82	55362	21200
	SH2 #3	11.88	0.1765	10,000,000	0.53	6.296	0.617	1,765,000	446127.95	1.66	292137	21200
	SH2 #7	24.47	0.1765	10,000,000	0.53	12.969	1.271	1,765,000	216591.74	3.43	68858	21200
	SH2 #8	18.43	0.1765	10,000,000	0.53	9.768	0.957	1,765,000	287574.61	2.58	121386	21200
*	SH2 #9	27.19								3.81		0
*	SH2 #10	27.29								3.82		0
	SH2 #12	7.05	0.1765	10,000,000	0.53	3.737	0.366	1,765,000	751773.05	0.99	829548	21200
	SH2 #13	7.05	0.1765	10,000,000	0.53	3.737	0.366	1,765,000	751773.05	0.99	829548	21200
	SH2 #14	4.83	0.1765	10,000,000	0.53	2.560	0.251	1,765,000	1097308.49	0.68	1767362	21200
	SH2 #15	15.51	0.1765	10,000,000	0.53	8.220	0.806	1,765,000	341715.02	2.17	171394	21200
	SH2 #16	15.91	0.1765	10,000,000	0.53	8.432	0.826	1,765,000	333123.82	2.23	162884	21200
	SH2 #17	15.91	0.1765	10,000,000	0.53	8.432	0.826	1,765,000	333123.82	2.23	162884	21200
	SH2 #50	10.88	0.1765	10,000,000	0.53	5.766	0.565	1,765,000	487132.35	1.52	348307	21200
	SH2 #52	26.28	0.1765	10,000,000	0.53	13.928	1.365	1,765,000	201674.28	3.68	59699	21200
	SH2 #57	13.90	0.1765	10,000,000	0.53	7.367	0.722	1,765,000	381294.96	1.95	213398	21200
	SH2 #58	3.83	0.1765	10,000,000	0.53	2.030	0.199	1,765,000	1383812.01	0.54	2810750	21200

Density = 0.098 lb/cu in
Modulus = 10,000,000 PSI
Shape = 1.5" X1.5" X 0.095 "

* Different Cross Section
** U-Channel
*** Grooved

AICPS Aluminum Chart

Component	Length in	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb.	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH3 #1	13.76	0.1765	10,000,000	0.53	7.293	0.715	1,765,000	385174.42	1.93	217762	21200
SH3 #2	5.02	0.1765	10,000,000	0.53	2.661	0.261	1,765,000	1055776.89	0.70	1636109	21200
SH3 #3	39.02	0.1765	10,000,000	0.53	20.681	2.027	1,765,000	135827.78	5.46	27080	21200
SH3 #4	18.16	0.1765	10,000,000	0.53	9.625	0.943	1,765,000	291850.22	2.54	125022	21200
SH3 #5	26.85	0.1765	10,000,000	0.53	14.231	1.395	1,765,000	197392.92	3.76	57191	21200
SH3 #6	7.73	0.1765	10,000,000	0.53	4.095	0.401	1,765,000	685995.34	1.08	690733	21200
SH3 #13	26.08	0.1765	10,000,000	0.53	13.822	1.355	1,765,000	203220.86	3.65	60618	21200
SH3 #14	7.73	0.1765	10,000,000	0.53	4.097	0.401	1,765,000	685640.36	1.08	690019	21200
SH3 #15	13.15	0.1765	10,000,000	0.53	6.970	0.683	1,765,000	403041.83	1.84	238434	21200
SH3 #16	5.79	0.1765	10,000,000	0.53	3.069	0.301	1,765,000	915371.33	0.81	1229880	21200
SH3 #17	19.32	0.1765	10,000,000	0.53	10.240	1.003	1,765,000	274327.12	2.70	110460	21200
SH3 #18	18.16	0.1765	10,000,000	0.53	9.625	0.943	1,765,000	291850.22	2.54	125022	21200
SH3 #19	25.88	0.1765	10,000,000	0.53	13.716	1.344	1,765,000	204791.34	3.62	61559	21200
SH3 #51	4.96	0.1765	10,000,000	0.53	2.629	0.258	1,765,000	1068548.39	0.69	1675932	21200
SH3 #53	23.06	0.1765	10,000,000	0.53	12.222	1.198	1,765,000	229835.21	3.23	77536	21200

Density = 0.098 lb/cu in
Modulus = 10,000,000 PSI
Shape = 1.5" X1.5" X 0.095 "

* Different Cross Section
** U-Channel
*** Grooved

AICPS Aluminum Chart

Component	Length in	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb.	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH4 #1	26.57	0.1765	10,000,000	0.53	14.082	1.380	1,765,000	199473.09	3.72	58403	21200
SH4 #2	7.76	0.1765	10,000,000	0.53	4.113	0.403	1,765,000	682989.69	1.09	684694	21200

Density = 0.098 lb/cu in
Modulus = 10,000,000 PSI
Shape = 1.5" X1.5" X 0.095 "

* Different Cross Section
** U-Channel
*** Grooved

AICPS Aluminum Chart

	Component	Length in	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb.	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH5 #1	18.10	0.1765	10,000,000	0.53	9.593	0.940	1,765,000	292817.68	2.53	125853	21200
	SH5 #4	15.30	0.1765	10,000,000	0.53	8.109	0.795	1,765,000	346405.23	2.14	176131	21200
	SH5 #5	9.72	0.1765	10,000,000	0.53	5.152	0.505	1,765,000	545267.49	1.36	436403	21200
	SH5 #7	3.93	0.1765	10,000,000	0.53	2.083	0.204	1,765,000	1348600.51	0.55	2669529	21200
	SH5 #9	26.57	0.1765	10,000,000	0.53	14.082	1.380	1,765,000	199473.09	3.72	58403	21200
	SH5 #10	13.13	0.1765	10,000,000	0.53	6.959	0.682	1,765,000	403655.75	1.84	239161	21200
***	SH5 #12	39.29								5.50		0
	SH5 #13	8.17	0.1765	10,000,000	0.53	4.330	0.424	1,765,000	648714.81	1.14	617697	21200
	SH5 #14	7.03	0.1765	10,000,000	0.53	3.726	0.365	1,765,000	753911.81	0.98	834275	21200
	SH5 #15	7.03	0.1765	10,000,000	0.53	3.726	0.365	1,765,000	753911.81	0.98	834275	21200
	SH5 #16	8.17	0.1765	10,000,000	0.53	4.330	0.424	1,765,000	648714.81	1.14	617697	21200
	SH5 #17	24.30	0.1765	10,000,000	0.53	12.879	1.262	1,765,000	218107.00	3.40	69824	21200
	SH5 #18	9.72	0.1765	10,000,000	0.53	5.152	0.505	1,765,000	545267.49	1.36	436403	21200
	SH5 #19	39.29	0.1765	10,000,000	0.53	20.824	2.041	1,765,000	134894.38	5.50	26709	21200

Density = 0.098 lb/cu in
Modulus = 10,000,000 PSI
Shape = 1.5" X1.5" X 0.095 "

* Different Cross Section
** U-Channel
*** Grooved

AICPS Aluminum Chart

Component	Length in	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb.	E I (Bending Stiffness) lb-in^2	EA/L (Tensile Stiffness) lb/in	$/ft (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH6 #1	31.95	0.1765	10,000,000	0.53	16.934	1.659	1,765,000	165884.19	4.47	40390	21200
SH6 #2	26.68	0.1765	10,000,000	0.53	14.140	1.386	1,765,000	198650.67	3.74	57923	21200
SH6 #3	17.84	0.1765	10,000,000	0.53	9.455	0.927	1,765,000	297085.20	2.50	129548	21200
SH6 #5	15.30	0.1765	10,000,000	0.53	8.109	0.795	1,765,000	346405.23	2.14	176131	21200
SH6 #6	6.00	0.1765	10,000,000	0.53	3.180	0.312	1,765,000	883333.33	0.84	1145295	21200
SH6 #7	7.76	0.1765	10,000,000	0.53	4.113	0.403	1,765,000	682989.69	1.09	684694	21200
SH6 #8	19.13	0.1765	10,000,000	0.53	10.139	0.994	1,765,000	277051.75	2.68	112665	21200
SH8 #3	8.48	0.1765	10,000,000	0.53	4.494	0.440	1,765,000	625000.00	1.19	573361	21200
* SH8 #4	6.51	0.1765	10,000,000	0.53	3.450	0.338	1,765,000	814132.10	0.91	972877	21200
SH8 #6	26.68	0.1765	10,000,000	0.53	14.140	1.386	1,765,000	198650.67	3.74	57923	21200
SH8 #7	12.93	0.1765	10,000,000	0.53	6.853	0.672	1,765,000	409899.46	1.81	246617	21200
SH8 #8	7.65	0.1765	10,000,000	0.53	4.055	0.397	1,765,000	692810.46	1.07	704526	21200
SH8 #9	9.93	0.1765	10,000,000	0.53	5.263	0.516	1,765,000	533736.15	1.39	418140	21200
SH8 #10	15.20	0.1765	10,000,000	0.53	8.056	0.789	1,765,000	348684.21	2.13	178457	21200
SH8 #11	6.51	1.42	10,000,000	1.06	6.901	0.676	14,200,000	1628264.21	0.91	7827110	42400
SH8 #12	6.51	1.42	10,000,000	1.06	6.901	0.676	14,200,000	1628264.21	0.91	7827110	42400
SH8 #50	4.96	0.1765	10,000,000	0.53	2.629	0.258	1,765,000	1068548.39	0.69	1675932	21200
SH8 #51	6.41	0.1765	10,000,000	0.53	3.397	0.333	1,765,000	826833.07	0.90	1003468	21200
SH8 #52	7.65	0.1765	10,000,000	0.53	4.055	0.397	1,765,000	692810.46	1.07	704526	21200

Density = 0.098 lb/cu in
Modulus = 10,000,000 PSI
Shape = 1.5" X1.5" X 0.095 "

* Different Cross Section
** U-Channel
*** Grooved

AICPS Aluminum Chart

	Component	Length in	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb.	E I (Bending Stiffness) lb-in^2	EA/L (Tensile Stiffness) lb/in	$/ft (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH9 #1	30.99	0.1765	10,000,000	0.53	16.425	1.610	1,765,000	171022.91	4.34	42932	21200
**	SH9 #2	39.15								5.48		0
**	SH9 #3	7.75								1.09		0
*	SH9 #4	18.59								2.60		0
	SH9 #6	6.71	0.1765	10,000,000	0.53	3.556	0.349	1,765,000	789865.87	0.94	915745	21200
	SH9 #8	23.14	0.1765	10,000,000	0.53	12.264	1.202	1,765,000	229040.62	3.24	77000	21200
	SH9 #9	17.97	0.1765	10,000,000	0.53	9.524	0.933	1,765,000	294936.00	2.52	127680	21200
	SH9 #10	26.03	0.1765	10,000,000	0.53	13.796	1.352	1,765,000	203611.22	3.64	60852	21200
*	SH9 #11	8.47								1.19		0
	SH9 #13	26.03	0.1765	10,000,000	0.53	13.796	1.352	1,765,000	203611.22	3.64	60852	21200
	SH9 #17	26.86	0.1765	10,000,000	0.53	14.236	1.395	1,765,000	197319.43	3.76	57149	21200
	SH9 #18	5.68	0.1765	10,000,000	0.53	3.010	0.295	1,765,000	933098.59	0.80	1277977	21200
	SH9 #19	19.34	0.1765	10,000,000	0.53	10.250	1.005	1,765,000	274043.43	2.71	110232	21200
	TOTAL	**1277.24**				**594.94**	**58.30**			**178.81**		

Density = 0.098 lb/cu in
Modulus = 10,000,000 PSI
Shape = 1.5" X1.5" X 0.095 "

* Different Cross Section
** U-Channel
*** Grooved

AICPS Graphite Chart

	Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft. (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH2 #2	27.29	0.12	15,000,000	0.56	15.282	0.856	1,800,000	307805.06	22.74	56460	117600
	SH2 #3	11.88	0.12	15,000,000	0.56	6.653	0.373	1,800,000	707070.71	9.90	297930	117600
	SH2 #7	24.47	0.12	15,000,000	0.56	13.703	0.767	1,800,000	343277.48	20.39	70223	117600
	SH2 #8	18.43	0.12	15,000,000	0.56	10.321	0.578	1,800,000	455778.62	15.36	123793	117600
*	SH2 #9	27.19	0.12	15,000,000	0.56		0.000			22.66	56876	117600
*	SH2 #10	27.29	0.12	15,000,000	0.56		0.000			22.74	56460	117600
	SH2 #12	7.05	0.12	15,000,000	0.56	3.948	0.221	1,800,000	1191489.36	5.88	845998	117600
	SH2 #13	7.05	0.12	15,000,000	0.56	3.948	0.221	1,800,000	1191489.36	5.88	845998	117600
	SH2 #14	4.83	0.12	15,000,000	0.56	2.705	0.151	1,800,000	1739130.43	4.03	1802409	117600
	SH2 #15	15.51	0.12	15,000,000	0.56	8.686	0.486	1,800,000	541586.07	12.93	174793	117600
	SH2 #16	15.91	0.12	15,000,000	0.56	8.910	0.499	1,800,000	527969.83	13.26	166114	117600
	SH2 #17	15.91	0.12	15,000,000	0.56	8.910	0.499	1,800,000	527969.83	13.26	166114	117600
	SH2 #50	10.88	0.12	15,000,000	0.56	6.093	0.341	1,800,000	772058.82	9.07	355214	117600
	SH2 #52	26.28	0.12	15,000,000	0.56	14.717	0.824	1,800,000	319634.70	21.90	60883	117600
	SH2 #57	13.90	0.12	15,000,000	0.56	7.784	0.436	1,800,000	604316.55	11.58	217630	117600
	SH2 #58	3.83	0.12	15,000,000	0.56	2.145	0.120	1,800,000	2193211.49	3.19	2866487	117600

Density = 0.056 lbs./cu. in.
Modulus = 15,000,000 PSI
Shape = 1.25" X1.25" X0.125"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Graphite Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) lb-in^2	EA/L (Tensile Stiffness) lb/in	$/ft. (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH3 #1	13.76	0.12	15,000,000	0.56	7.706	0.432	1,800,000	610465.12	11.47	222081	117600
SH3 #2	5.02	0.12	15,000,000	0.56	2.811	0.157	1,800,000	1673306.77	4.18	1668553	117600
SH3 #3	39.02	0.12	15,000,000	0.56	21.851	1.224	1,800,000	215274.22	32.52	27617	117600
SH3 #4	18.16	0.12	15,000,000	0.56	10.170	0.569	1,800,000	462555.07	15.13	127502	117600
SH3 #5	26.85	0.12	15,000,000	0.56	15.036	0.842	1,800,000	312849.16	22.38	58326	117600
SH3 #6	7.73	0.12	15,000,000	0.56	4.327	0.242	1,800,000	1087237.90	6.44	704431	117600
SH3 #13	26.08	0.12	15,000,000	0.56	14.605	0.818	1,800,000	322085.89	21.73	61820	117600
SH3 #14	7.73	0.12	15,000,000	0.56	4.329	0.242	1,800,000	1086675.29	6.44	703702	117600
SH3 #15	13.15	0.12	15,000,000	0.56	7.364	0.412	1,800,000	638783.27	10.96	243162	117600
SH3 #16	5.79	0.12	15,000,000	0.56	3.242	0.182	1,800,000	1450777.20	4.83	1254268	117600
SH3 #17	19.32	0.12	15,000,000	0.56	10.819	0.606	1,800,000	434782.61	16.10	112651	117600
SH3 #18	18.16	0.12	15,000,000	0.56	10.170	0.569	1,800,000	462555.07	15.13	127502	117600
SH3 #19	25.88	0.12	15,000,000	0.56	14.493	0.812	1,800,000	324574.96	21.57	62780	117600
SH3 #51	4.96	0.12	15,000,000	0.56	2.778	0.156	1,800,000	1693548.39	4.13	1709166	117600
SH3 #53	23.06	0.12	15,000,000	0.56	12.914	0.723	1,800,000	364267.13	19.22	79073	117600

Density = 0.056 lbs./cu. in.
Modulus = 15,000,000 PSI
Shape = 1.25" X1.25" X0.125"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Graphite Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft. (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH4 #1	26.57	0.12	15,000,000	0.56	14.879	0.833	1,800,000	316146.03	22.14	59561	117600
SH4 #2	7.76	0.12	15,000,000	0.56	4.346	0.243	1,800,000	1082474.23	6.47	698271	117600

Density = 0.056 lbs./cu. in.
Modulus = 15,000,000 PSI
Shape = 1.25" X1.25" X0.125"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Graphite Chart

	Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft. (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH5 #1	18.10	0.12	15,000,000	0.56	10.136	0.568	1,800,000	464088.40	15.08	128348	117600
	SH5 #4	15.30	0.12	15,000,000	0.56	8.568	0.480	1,800,000	549019.61	12.75	179624	117600
	SH5 #5	9.72	0.12	15,000,000	0.56	5.443	0.305	1,800,000	864197.53	8.10	445056	117600
	SH5 #7	3.93	0.12	15,000,000	0.56	2.201	0.123	1,800,000	2137404.58	3.28	2722466	117600
	SH5 #9	26.57	0.12	15,000,000	0.56	14.879	0.833	1,800,000	316146.03	22.14	59561	117600
	SH5 #10	13.13	0.12	15,000,000	0.56	7.353	0.412	1,800,000	639756.28	10.94	243904	117600
***	SH5 #12	39.29	0.12	15,000,000	0.56		0.000			32.74	27239	117600
	SH5 #13	8.17	0.12	15,000,000	0.56	4.575	0.256	1,800,000	1028151.77	6.81	629946	117600
	SH5 #14	7.03	0.12	15,000,000	0.56	3.937	0.220	1,800,000	1194879.09	5.86	850818	117600
	SH5 #15	7.03	0.12	15,000,000	0.56	3.937	0.220	1,800,000	1194879.09	5.86	850818	117600
	SH5 #16	8.17	0.12	15,000,000	0.56	4.575	0.256	1,800,000	1028151.77	6.81	629946	117600
	SH5 #17	24.30	0.12	15,000,000	0.56	13.608	0.762	1,800,000	345679.01	20.25	71209	117600
	SH5 #18	9.72	0.12	15,000,000	0.56	5.443	0.305	1,800,000	864197.53	8.10	445056	117600
	SH5 #19	39.29	0.12	15,000,000	0.56	22.002	1.232	1,800,000	213794.86	32.74	27239	117600

Density = 0.056 lbs./cu. in.
Modulus = 15,000,000 PSI
Shape = 1.25" X1.25" X0.125"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Graphite Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft. (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH6 #1	31.95	0.12	15,000,000	0.56	17.892	1.002	1,800,000	262910.80	26.63	41191	117600
SH6 #2	26.68	0.12	15,000,000	0.56	14.941	0.837	1,800,000	314842.58	22.23	59071	117600
SH6 #3	17.84	0.12	15,000,000	0.56	9.990	0.559	1,800,000	470852.02	14.87	132117	117600
SH6 #5	15.30	0.12	15,000,000	0.56	8.568	0.480	1,800,000	549019.61	12.75	179624	117600
SH6 #6	6.00	0.12	15,000,000	0.56	3.360	0.188	1,800,000	1400000.00	5.00	1168006	117600
SH6 #7	7.76	0.12	15,000,000	0.56	4.346	0.243	1,800,000	1082474.23	6.47	698271	117600
SH6 #8	19.13	0.12	15,000,000	0.56	10.713	0.600	1,800,000	439100.89	15.94	114899	117600
SH8 #3	8.48	0.12	15,000,000	0.56	4.749	0.266	1,800,000	990566.04	7.07	584731	117600
* SH8 #4	6.51	0.12	15,000,000	0.56	3.646	0.204	1,800,000	1290322.58	5.43	992169	117600
SH8 #6	26.68	0.12	15,000,000	0.56	14.941	0.837	1,800,000	314842.58	22.23	59071	117600
SH8 #7	12.93	0.12	15,000,000	0.56	7.241	0.405	1,800,000	649651.97	10.78	251507	117600
SH8 #8	7.65	0.12	15,000,000	0.56	4.284	0.240	1,800,000	1098039.22	6.38	718497	117600
SH8 #9	9.93	0.12	15,000,000	0.56	5.561	0.311	1,800,000	845921.45	8.28	426431	117600
SH8 #10	15.20	0.12	15,000,000	0.56	8.512	0.477	1,800,000	552631.58	12.67	181995	117600
* SH8 #11	6.51								5.43		
* SH8 #12	6.51								5.43		
SH8 #50	4.96	0.12	15,000,000	0.56	2.778	0.156	1,800,000	1693548.39	4.13	1709166	117600
SH8 #51	6.41	0.12	15,000,000	0.56	3.590	0.201	1,800,000	1310452.42	5.34	1023367	117600
SH8 #52	7.65	0.12	15,000,000	0.56	4.284	0.240	1,800,000	1098039.22	6.38	718497	117600

Density = 0.056 lbs./cu. in.
Modulus = 15,000,000 PSI
Shape = 1.25" X1.25" X0.125"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Graphite Chart

	Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/ft. (Price/ft.)	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH9 #1	30.99	0.12	15,000,000	0.56	17.354	0.972	1,800,000	271055.18	25.83	43783	117600
**	SH9 #2	39.15	0.12	15,000,000	0.56		0.000			32.63	27434	117600
**	SH9 #3	7.75	0.12	15,000,000	0.56		0.000			6.46	700074	117600
*	SH9 #4	18.59	0.12	15,000,000	0.56		0.000			15.49	121671	117600
	SH9 #6	6.71	0.12	15,000,000	0.56	3.758	0.210	1,800,000	1251862.89	5.59	933905	117600
	SH9 #8	23.14	0.12	15,000,000	0.56	12.958	0.726	1,800,000	363007.78	19.28	78527	117600
	SH9 #9	17.97	0.12	15,000,000	0.56	10.063	0.564	1,800,000	467445.74	14.98	130212	117600
	SH9 #10	26.03	0.12	15,000,000	0.56	14.577	0.816	1,800,000	322704.57	21.69	62058	117600
*	SH9 #11	8.47	0.12	15,000,000	0.56		0.000			7.06	586112	117600
	SH9 #13	26.03	0.12	15,000,000	0.56	14.577	0.816	1,800,000	322704.57	21.69	62058	117600
	SH9 #17	26.86	0.12	15,000,000	0.56	15.042	0.842	1,800,000	312732.69	22.38	58282	117600
	SH9 #18	5.68	0.12	15,000,000	0.56	3.181	0.178	1,800,000	1478873.24	4.73	1303320	117600
	SH9 #19	19.34	0.12	15,000,000	0.56	10.830	0.607	1,800,000	434332.99	16.12	112418	117600
	TOTAL	**1277.24**				**614.03**	**34.39**			**1064.36**		

Density = 0.056 lbs./cu. in.
Modulus = 15,000,000 PSI
Shape = 1.25" X1.25" X0.125"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Glass Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) lb-in^2	EA/L (Tensile Stiffness) lb/in	$/Foot	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH2 #2	27.29	1.92	2,500,000	2.25	61.403	3.991	4,800,000	206119.46	15.92	150560	67500
SH2 #3	11.88	1.92	2,500,000	2.25	26.730	1.737	4,800,000	473484.85	6.93	794481	67500
SH2 #7	24.47	1.92	2,500,000	2.25	55.058	3.579	4,800,000	229873.31	14.27	187261	67500
SH2 #8	18.43	1.92	2,500,000	2.25	41.468	2.695	4,800,000	305208.90	10.75	330115	67500
* SH2 #9	27.19	1.92	2,500,000	2.25		0.000			15.86	151669	67500
* SH2 #10	27.29	1.92	2,500,000	2.25		0.000			15.92	150560	67500
SH2 #12	7.05	1.92	2,500,000	2.25	15.863	1.031	4,800,000	797872.34	4.11	2255995	67500
SH2 #13	7.05	1.92	2,500,000	2.25	15.863	1.031	4,800,000	797872.34	4.11	2255995	67500
SH2 #14	4.83	1.92	2,500,000	2.25	10.868	0.706	4,800,000	1164596.27	2.82	4806424	67500
SH2 #15	15.51	1.92	2,500,000	2.25	34.898	2.268	4,800,000	362669.25	9.05	466115	67500
SH2 #16	15.91	1.92	2,500,000	2.25	35.798	2.327	4,800,000	353551.23	9.28	442972	67500
SH2 #17	15.91	1.92	2,500,000	2.25	35.798	2.327	4,800,000	353551.23	9.28	442972	67500
SH2 #50	10.88	1.92	2,500,000	2.25	24.480	1.591	4,800,000	517003.68	6.35	947237	67500
SH2 #52	26.28	1.92	2,500,000	2.25	59.130	3.843	4,800,000	214041.10	15.33	162355	67500
SH2 #57	13.90	1.92	2,500,000	2.25	31.275	2.033	4,800,000	404676.26	8.11	580346	67500
SH2 #58	3.83	1.92	2,500,000	2.25	8.618	0.560	4,800,000	1468668.41	2.23	7643966	67500

Density = 0.065 lbs./cu. in.
Modulus = 2,500,000 PSI
Shape = 2.5" X 2.5" X 0.25"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Glass Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) lb-in^2	EA/L (Tensile Stiffness) lb/in	$/Foot	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH3 #1	13.76	1.92	2,500,000	2.25	30.960	2.012	4,800,000	408793.60	8.03	592215	67500
SH3 #2	5.02	1.92	2,500,000	2.25	11.295	0.734	4,800,000	1120517.93	2.93	4449476	67500
SH3 #3	39.02	1.92	2,500,000	2.25	87.795	5.707	4,800,000	144156.84	22.76	73645	67500
SH3 #4	18.16	1.92	2,500,000	2.25	40.860	2.656	4,800,000	309746.70	10.59	340004	67500
SH3 #5	26.85	1.92	2,500,000	2.25	60.413	3.927	4,800,000	209497.21	15.66	155535	67500
SH3 #6	7.73	1.92	2,500,000	2.25	17.384	1.130	4,800,000	728061.09	4.51	1878481	67500
SH3 #13	26.08	1.92	2,500,000	2.25	58.680	3.814	4,800,000	215682.52	15.21	164855	67500
SH3 #14	7.73	1.92	2,500,000	2.25	17.393	1.131	4,800,000	727684.35	4.51	1876538	67500
SH3 #15	13.15	1.92	2,500,000	2.25	29.588	1.923	4,800,000	427756.65	7.67	648433	67500
SH3 #16	5.79	1.92	2,500,000	2.25	13.028	0.847	4,800,000	971502.59	3.38	3344715	67500
SH3 #17	19.32	1.92	2,500,000	2.25	43.470	2.826	4,800,000	291149.07	11.27	300401	67500
SH3 #18	18.16	1.92	2,500,000	2.25	40.860	2.656	4,800,000	309746.70	10.59	340004	67500
SH3 #19	25.88	1.92	2,500,000	2.25	58.230	3.785	4,800,000	217349.30	15.10	167412	67500
SH3 #51	4.96	1.92	2,500,000	2.25	11.160	0.725	4,800,000	1134072.58	2.89	4557776	67500
SH3 #53	23.06	1.92	2,500,000	2.25	51.885	3.373	4,800,000	243928.88	13.45	210862	67500

Density = 0.065 lbs./cu. in.
Modulus = 2,500,000 PSI
Shape = 2.5" X 2.5" X 0.25"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Glass Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/Foot	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH4 #1	26.57	1.92	2,500,000	2.25	59.783	3.886	4,800,000	211704.93	15.50	158830	67500
SH4 #2	7.76	1.92	2,500,000	2.25	17.460	1.135	4,800,000	724871.13	4.53	1862057	67500

Density = 0.065 lbs./cu. in.
Modulus = 2,500,000 PSI
Shape = 2.5" X 2.5" X 0.25"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Glass Chart

	Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/Foot	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH5 #1	18.10	1.92	2,500,000	2.25	40.725	2.647	4,800,000	310773.48	10.56	342262	67500
	SH5 #4	15.30	1.92	2,500,000	2.25	34.425	2.238	4,800,000	367647.06	8.93	478998	67500
	SH5 #5	9.72	1.92	2,500,000	2.25	21.870	1.422	4,800,000	578703.70	5.67	1186817	67500
	SH5 #7	3.93	1.92	2,500,000	2.25	8.843	0.575	4,800,000	1431297.71	2.29	7259909	67500
	SH5 #9	26.57	1.92	2,500,000	2.25	59.783	3.886	4,800,000	211704.93	15.50	158830	67500
	SH5 #10	13.13	1.92	2,500,000	2.25	29.543	1.920	4,800,000	428408.23	7.66	650409	67500
***	SH5 #12	39.29	1.92	2,500,000	2.25		0.000			22.92	72636	67500
	SH5 #13	8.17	1.92	2,500,000	2.25	18.383	1.195	4,800,000	688494.49	4.77	1679857	67500
	SH5 #14	7.03	1.92	2,500,000	2.25	15.818	1.028	4,800,000	800142.25	4.10	2268849	67500
	SH5 #15	7.03	1.92	2,500,000	2.25	15.818	1.028	4,800,000	800142.25	4.10	2268849	67500
	SH5 #16	8.17	1.92	2,500,000	2.25	18.383	1.195	4,800,000	688494.49	4.77	1679857	67500
	SH5 #17	24.30	1.92	2,500,000	2.25	54.675	3.554	4,800,000	231481.48	14.18	189891	67500
	SH5 #18	9.72	1.92	2,500,000	2.25	21.870	1.422	4,800,000	578703.70	5.67	1186817	67500
	SH5 #19	39.29	1.92	2,500,000	2.25	88.403	5.746	4,800,000	143166.20	22.92	72636	67500

Density = 0.065 lbs./cu. in.
Modulus = 2,500,000 PSI
Shape = 2.5" X 2.5" X 0.25"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Glass Chart

Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) lb-in^2	EA/L (Tensile Stiffness) lb/in	$/Foot	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
SH6 #1	31.95	1.92	2,500,000	2.25	71.888	4.673	4,800,000	176056.34	18.64	109844	67500
SH6 #2	26.68	1.92	2,500,000	2.25	60.030	3.902	4,800,000	210832.08	15.56	157523	67500
SH6 #3	17.84	1.92	2,500,000	2.25	40.140	2.609	4,800,000	315302.69	10.41	352311	67500
SH6 #5	15.30	1.92	2,500,000	2.25	34.425	2.238	4,800,000	367647.06	8.93	478998	67500
SH6 #6	6.00	1.92	2,500,000	2.25	13.500	0.878	4,800,000	937500.00	3.50	3114683	67500
SH6 #7	7.76	1.92	2,500,000	2.25	17.460	1.135	4,800,000	724871.13	4.53	1862057	67500
SH6 #8	19.13	1.92	2,500,000	2.25	43.043	2.798	4,800,000	294040.77	11.16	306398	67500
SH8 #3	8.48	1.92	2,500,000	2.25	19.080	1.240	4,800,000	663325.47	4.95	1559282	67500
* SH8 #4	6.51	1.92	2,500,000	2.25	14.648	0.952	4,800,000	864055.30	3.80	2645784	67500
SH8 #6	26.68	1.92	2,500,000	2.25	60.030	3.902	4,800,000	210832.08	15.56	157523	67500
SH8 #7	12.93	1.92	2,500,000	2.25	29.093	1.891	4,800,000	435034.80	7.54	670686	67500
SH8 #8	7.65	1.92	2,500,000	2.25	17.213	1.119	4,800,000	735294.12	4.46	1915991	67500
SH8 #9	9.93	1.92	2,500,000	2.25	22.343	1.452	4,800,000	566465.26	5.79	1137150	67500
SH8 #10	15.20	1.92	2,500,000	2.25	34.200	2.223	4,800,000	370065.79	8.87	485321	67500
* SH8 #11	6.51	1.92		2.25					3.80		
* SH8 #12	6.51	1.92		2.25					3.80		
SH8 #50	4.96	1.92	2,500,000	2.25	11.160	0.725	4,800,000	1134072.58	2.89	4557776	67500
SH8 #51	6.41	1.92	2,500,000	2.25	14.423	0.937	4,800,000	877535.10	3.74	2728979	67500
SH8 #52	7.65	1.92	2,500,000	2.25	17.213	1.119	4,800,000	735294.12	4.46	1915991	67500

Density = 0.065 lbs./cu. in.
Modulus = 2,500,000 PSI
Shape = 2.5" X 2.5" X 0.25"

* Different Cross-Section
** U-Channel
*** Grooved

AICPS Glass Chart

	Component	Length	I (Inertia) in^4	E (Modulus) PSI	Area in^2	Volume in^3	Mass lb	E I (Bending Stiffness) $lb\text{-}in^2$	EA/L (Tensile Stiffness) lb/in	$/Foot	F (Column Buckling) lb	P (@75°F) (Yield Stress x Area) lb
	SH9 #1	30.99	1.92	2,500,000	2.25	69.728	4.532	4,800,000	181510.16	18.08	116754	67500
**	SH9 #2	39.15	1.92	2,500,000	2.25		0.000			22.84	73156	67500
**	SH9 #3	7.75	1.92	2,500,000	2.25		0.000			4.52	1866865	67500
*	SH9 #4	18.59	1.92	2,500,000	2.25		0.000			10.84	324457	67500
	SH9 #6	6.71	1.92	2,500,000	2.25	15.098	0.981	4,800,000	838301.04	3.91	2490412	67500
	SH9 #8	23.14	1.92	2,500,000	2.25	52.065	3.384	4,800,000	243085.57	13.50	209406	67500
	SH9 #9	17.97	1.92	2,500,000	2.25	40.433	2.628	4,800,000	313021.70	10.48	347232	67500
	SH9 #10	26.03	1.92	2,500,000	2.25	58.568	3.807	4,800,000	216096.81	15.18	165489	67500
*	SH9 #11	8.47	1.92	2,500,000	2.25		0.000			4.94	1562966	67500
	SH9 #13	26.03	1.92	2,500,000	2.25	58.568	3.807	4,800,000	216096.81	15.18	165489	67500
	SH9 #17	26.86	1.92	2,500,000	2.25	60.435	3.928	4,800,000	209419.21	15.67	155419	67500
	SH9 #18	5.68	1.92	2,500,000	2.25	12.780	0.831	4,800,000	990316.90	3.31	3475519	67500
	SH9 #19	19.34	1.92	2,500,000	2.25	43.515	2.828	4,800,000	290847.98	11.28	299780	67500
	TOTAL	**1277.24**				**2467.09**	**160.36**			**745.05**		

Density = 0.065 lbs./cu. in.
Modulus = 2,500,000 PSI
Shape = 2.5" X 2.5" X 0.25"

* Different Cross-Section
** U-Channel
*** Grooved

Appendix C:

Processing Steps for Systems

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Systems A through C: Process Steps

1. Manufacturing/purchase of graphite beams.
2. Purchase of EMI mesh.
3. Manufacturing/purchase of skin/honeycomb panels. EMI mesh incorporated into panels by vendor.
4. Purchase of 2-, 3-, and 4-way connectors.
5. Machining: trim panels, cut-outs, and drill holes in panels, and beams.
6. Assembly of composite beam frame (adhesive and/or mechanical fasteners).
7. Curing of adhesive.
8. Bonding/fastening of panels to frame.
9. Chemical Agent Reactive Coating (CARC) paint.

Systems D and E: Process Steps

1. Manufacturing/purchase of graphite beams.
2. Purchase of EMI mesh.
3. Purchase of dry fabric and resin or prepreg.
4. Purchase of connectors.
5. Lay-up of composite side panels.
6. Cure of panels.
7. Machining: trim panels, cut-outs, and drill holes in panels, and beams.
8. Assembly of composite beam frame (adhesive and/or mechanical fasteners).
9. Curing of adhesive.
10. Bonding/fastening of panels to frame.
11. CARC paint.

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D. M. Spagnuolo, R. B. Dooley, T. A. Bogetti, and E. J. Rigas

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U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
Aberdeen Proving Ground, MD 21005-5069

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13. ABSTRACT *(Maximum 200 words)*

This report documents the efforts involved in determining the feasibility of substituting aluminum components with organic matrix composites for application to the Advanced Integrated Collective Protection System (AICPS) container. The AICPS container houses an air filtration/power generation system capable of providing a temperature-controlled air supply free of nuclear, biological, and chemical (NBC) contaminants to tactical vehicles and shelters.

This study was undertaken to investigate the potential of enhancing the performance of the AICPS container in terms of portability (weight), economy (cost and life cycle), detection, and reliability (noise and electromagnetic impulse/interference protection). The objective was to determine if composite materials would enhance system performance and, if so, to what degree and at what cost.

Efforts to maintain original system geometry and performance specifications resulted in two approaches. Results indicate that the application of certain composites to the AICPS container would enhance performance in terms of weight. However, the increased cost of both the raw materials and of manufacturing the structure, subject to the geometric constraints, was considered inefficient. A significant increase in weight savings could be achieved, at a more reasonable cost, if geometric constraints were eliminated to allow for rearranging the distribution and orientation of internal components.

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